

1. OVERVIEW

This final report summarizes work carried out during my PGG funding for the period 3/1/02 – 2/28/05. Research under this award has focused on the areas described below and is represented in the publications list, invited departmental lectures and presentations at professional meetings. The grant has provided partial support for 1 graduate student, Renee Bulow, and provided 1 month per year of my summer salary.

The linking theme of the research performed under this award is the manifestation of the thermal history of terrestrial planetary bodies through the existence and evolution of internally-generated magnetic fields (martian magnetism research, and beginnings of lunar magnetism research), mantle dynamical processes and their resulting surface expression (studies of venusian coronae task) and the crust and upper mantle structure of a planetary body (lunar seismic structure task). The investigations build upon and extend my previous work supported by the PGG program.

2. RESEARCH PERFORMED UNDER THIS AWARD

Publications and abstracts associated with this work are listed below.

- (1) Studies of venusian corona. I have examined the spatial distribution of coronae and its relationship to possibly changing large-scale mantle dynamic processes (published JGR paper).
- (2) Processing of the lunar Apollo seismic event and continuous data. This work is being carried out primarily by my student Renee Bulow, under my guidance and in collaboration with Professor Peter Shearer at IGPP. This has led to the discovery of previously undetected moonquakes associated with known deep clusters (JGR paper, in revision).
- (3) Lunar paleointensity. In November 2003 I visited JSC, with colleague Dr. Jeff Gee, to survey the natural remanent magnetization of a suite of Apollo samples. We measured 17 samples – most display some magnetic signature. We requested a subset of these samples from CAPTEM for preliminary paleointensity measurements at Scripps. The samples were received in summer 2004 and our lab work is in its early stages.
- (4) A study, in collaboration with Roger Phillips, of the magnetic signatures over the Tharsis region on Mars. Mars Global Surveyor (MGS) observations of crustal magnetic fields over Tharsis provide new constraints on models for the thermal and magmatic evolution of this region (published EPSL manuscript). This work has also contributed to the review paper on the early history of Mars by *Solomon et al.* (published Science paper).

3. INVITED LECTURES / PRESENTATIONS ON THIS RESEARCH

2004: University of California, Berkeley, Seismo Lab Seminar
 Scripps Institution Inaugural Lecture
 University of Toronto, Physics Department Colloquium
 University of British Columbia, Earth and Ocean Sciences seminar

2002: University of Michigan, Dept. Geological Sciences
University of Edinburgh, Invited Swiney Lecture Series
University of California, Los Angeles, planetary science seminar series.

4. PUBLICATIONS UNDER THIS AWARD

Peer Reviewed Publications

- Johnson, C. L. & M. R. Richards, A Conceptual Model For The Relationship Between Coronae And Large-Scale Mantle Dynamics On Venus, *JGR Planets*, **108** (E6), doi: 10.1029/2002JE001962, 2003
- Johnson, C. L., & R. J. Phillips, Evolution of the Tharsis Region of Mars: Insights from Magnetic Field Observations, *Earth and Planet. Sci. Lett.*, **230**, 241-254, 2004
- Solomon, S. C., O. Aharonson, J. M. Aurnou, W. B. Banerdt, M. H. Carr, A. J. Dombard, H. V. Frey, M. P. Golombek, S. A. Hauck, J. W. Head, B. Jakosky, C. L. Johnson, P. J. McGovern, G. A. Neumann, R. J. Phillips, D. E. Smith, M. T. Zuber. New Perspectives on Ancient Mars, *Science*, **307**, 1214-1220, 2005
- Bulow, R., C. L. Johnson, & P. Shearer. Previously Unidentified Moonquakes. In revision, for *J. Geophys. Res. Planets*, 2005

Abstracts (papers presented at professional meetings)

- Johnson, C. L. & M. R. Richards, A Conceptual Model For The Relationship Between Coronae And Large-Scale Mantle Dynamics On Venus. In *Lunar and Planetary Science XXXIII*, Abstract # 1733, Lunar and Planetary Institute Houston (CD-ROM), 2002.
- Johnson, C. L. & S. C. Solomon, A Global Gravity Study Of Coronae On Venus, In *Lunar and Planetary Science XXXIII*, Abstract # 1952, Lunar and Planetary Institute Houston (CD-ROM), 2002.
- Solomon, S. C., O. Aharonson, J. M. Aurnou, W. B. Banerdt, M. H. Carr, A.J. Dombard, H.V. Frey, M. P. Golombek, S. A. Hauck, II, J. W. Head, III, W. E. Hutchison, B. M. Jakosky, C. L. Johnson, Patrick J. McGovern, G. A. Neumann, R. J. Phillips, M. A. Richards, D. E. Smith, M. T. Zuber, Insights into the Earliest History of Mars: A New Synthesis, In *Lunar and Planetary Science XXXIII*, Abstract # 1687, Lunar and Planetary Institute Houston (CD-ROM), 2002.
- Dombard, A.J., C.L Johnson, M.A. Richards, and S.C. Solomon, A transient plume melting model for coronae on Venus, *Lunar Planet. Sci.* [CD-ROM], XXXIII, abstract 1877, 2002.
- Bulow, R., C. L. Johnson & P. S. Shearer. Comprehensive Processing of the Apollo Seismic Event Data, In *Lunar and Planetary Science XXXIV*, Abstract #1138, Lunar and Planetary Institute Houston (CD-ROM), 2003.
- Johnson, C. L. & R. J. Phillips. Constraints on the Evolution of the Tharsis Region of Mars. In *Lunar and Planetary Science XXXIV*, Abstract # 1360, Lunar and Planetary Institute Houston (CD-ROM), 2003.

- Solomon, S. C., O. Aharonson, W.B. Banerdt, A.J. Dombard, H.V. Frey, M.P. Golombek, S.A. Hauck, II, J.W. Head, III, C.L. Johnson, P.J. McGovern, R.J. Phillips, D.E. Smith, & M.T. Zuber, Why Are There So Few Magnetic Anomalies in Martian Lowlands and Basins? In *Lunar and Planetary Science XXXIV*, Abstract # 1382, Lunar and Planetary Institute Houston (CD-ROM), 2003
- Johnson, C. L. & R. J. Phillips. The Tharsis Region of Mars: New Insights From Magnetic Field Observations, Sixth International Conference on Mars, In *Lunar and Planetary Science XXXIV*, Abstract # 3065, Lunar and Planetary Institute Houston (CD-ROM), 2003.
- Phillips, R. J., C. L. Johnson, B. M. Hynek, & B. M. Jakosky, Noachian Evolution of Mars, Sixth International Conference on Mars, Abstract # 3021, Lunar and Planetary Institute Houston (CD-ROM), 2003.
- Bulow, R. C., C. L. Johnson, & P. M. Shearer. New Events Discovered in the Apollo Seismic Data. In *Lunar and Planetary Science XXXV*, Abstract # 1184, Lunar and Planetary Institute Houston (CD-ROM), 2004.
- Phillips, R. J., C. L. Johnson and A. J. Dombard. Localized Tharsis Loading on Mars: Testing the Membrane Surface Hypothesis, In *Lunar and Planetary Science XXXV*, Abstract # 1427, Lunar and Planetary Institute Houston (CD-ROM), 2004.
- Johnson, C. L. & R. J. Phillips. Mars' Magnetic Field: Implications for Crustal Formation and Evolution. *Eos Trans. AGU*, 85(17), Jt. Assem. Suppl., Abstract 1913, 2004.
- Johnson, C. L., R. Bulow, P. Shearer, C. Lithgow-Bertelloni & L. Stixrude. Mineralogical and Seismological Models of the Lunar Mantle. *Studies of the Earth's Deep Interior*, Abstract # S8.6, 2004.

5. EDUCATION AND OUTREACH

We have developed several visualization objects and tools for the Scripps Visualization Center (<http://siovizcenter.ucsd.edu>), including flythroughs of Mars' topography, and visualizations incorporating several data sets related to the MER landing sites. This has resulted in the following publication

Schwehr, K., C. Johnson, D. Kilb, A. Nayak, C. Nishimura. Visualization tools facilitate geological investigations of Mars exploration rover landing sites. IS&T/SPIE Paper Number 5669-15, San Jose, CA., 17-Jan-2005

6. RELEVANCE TO NASA GOALS

The completed work is directly relevant to NASA's goals of understanding the formation and evolution of the terrestrial planets. The investigations have addressed aspects of fundamental questions related to the thermal evolution of the moon using state-of-the art seismological techniques applied to the unique Apollo data sets. In addition they have provided new insights understanding the evolution of mantle dynamics of Venus, and the magnetic field history and volcanic evolution of Mars.